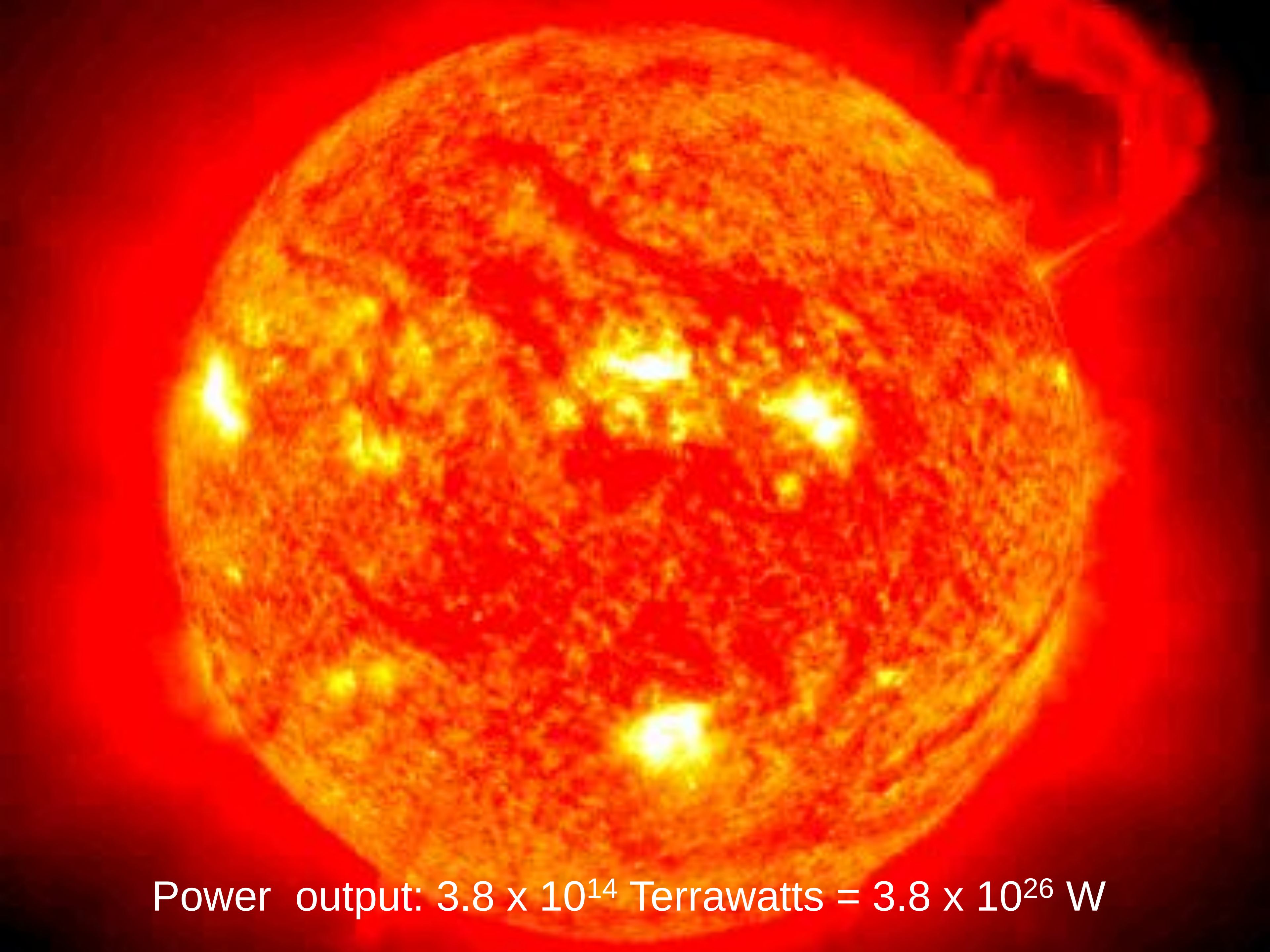
Solar power generation and solar chemistry

Energy focus

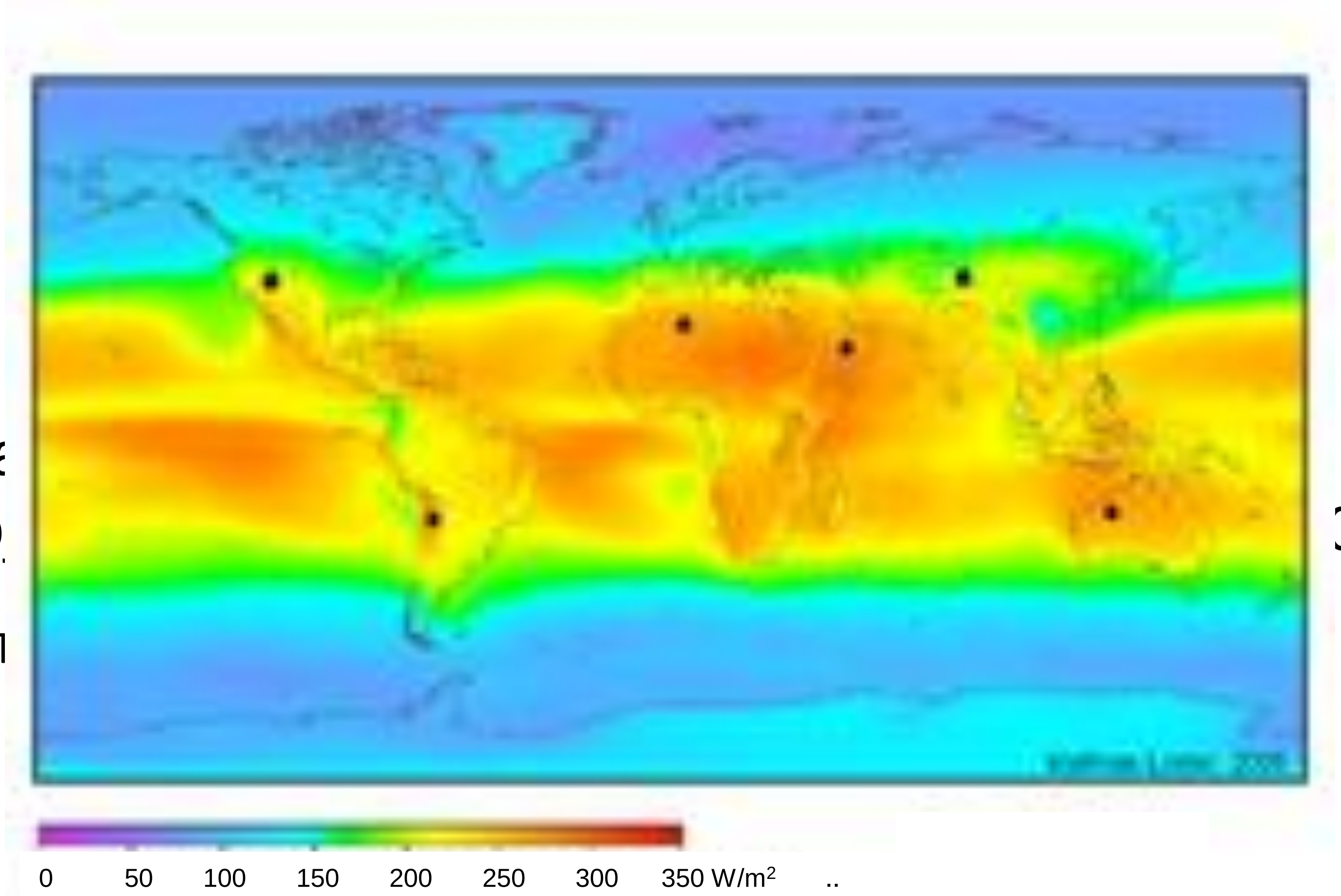
Department of Physics



Power output: 3.8×10^{14} Terrawatts = 3.8×10^{26} W

Some numbers

Solar constant (in earth's orbit) ~ 1.4 kW/m2



Tota GW

Pro 0 GW

- T

- Projected energy supply in the future requires
  - At 100 % efficiency within the UK: ~ 1.400 km^2
  - At 100% in Sahara ~ 467 km^2

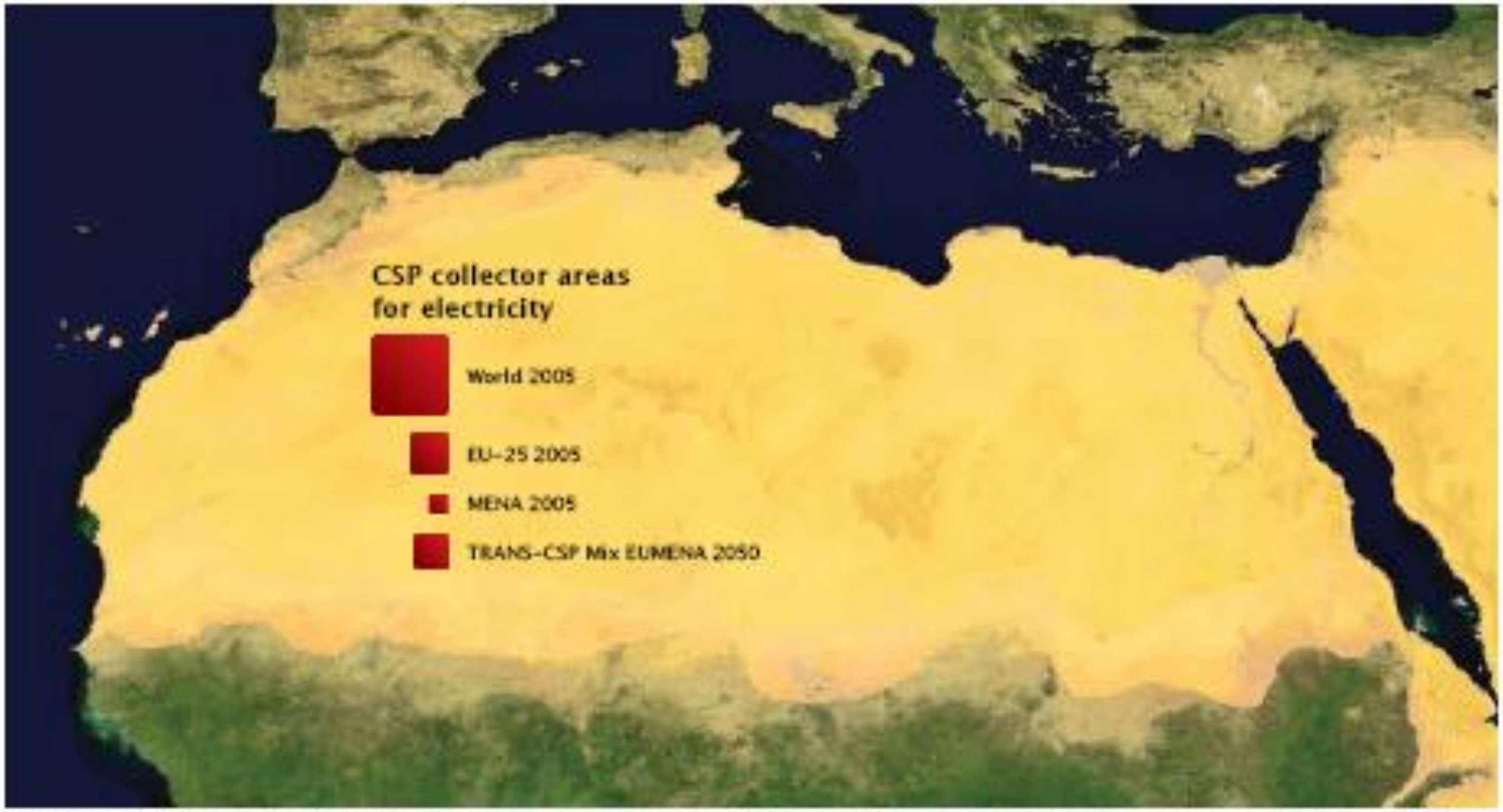


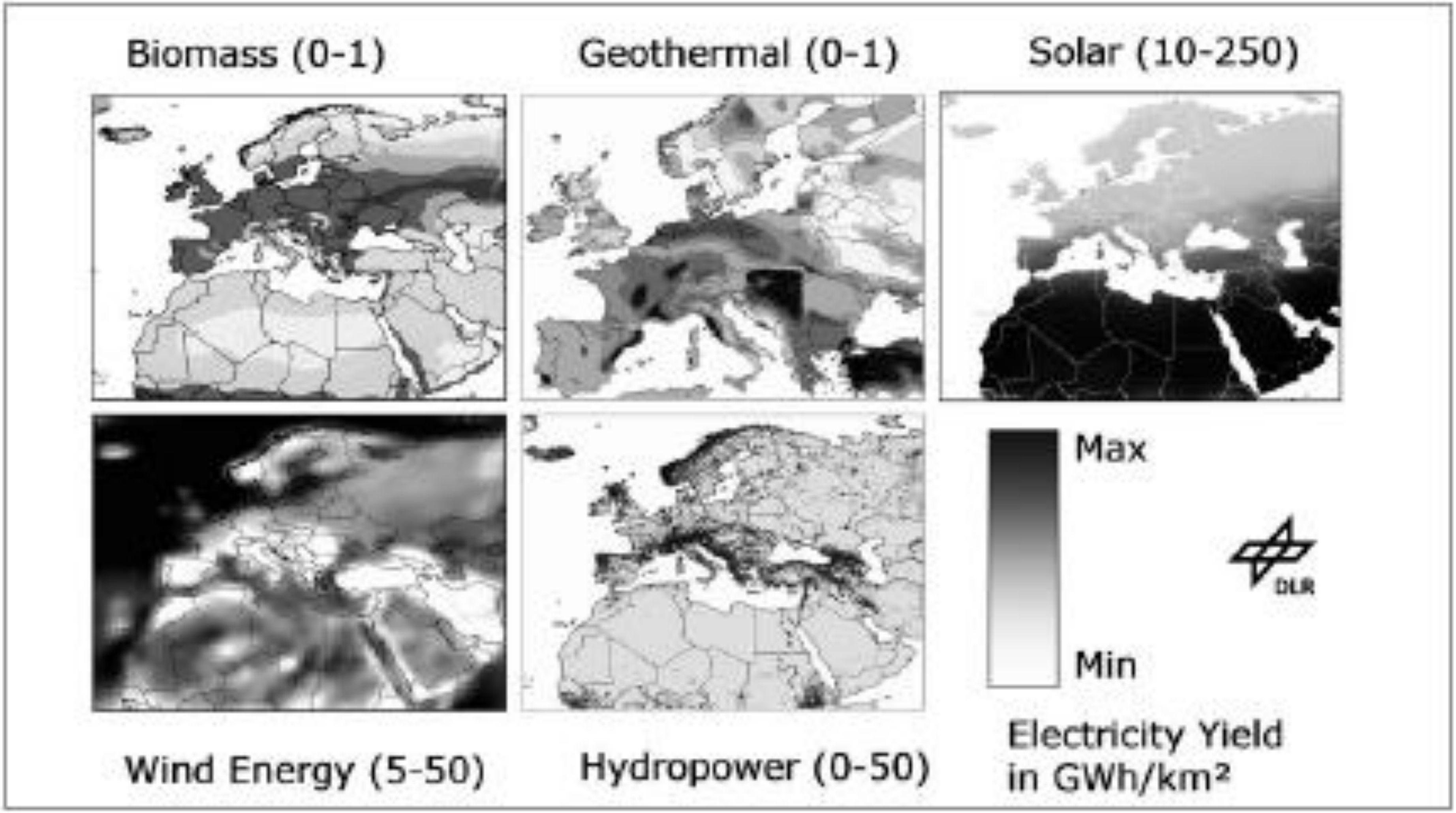
Figure 2: Areas of the size as indicated by the red squares would be sufficient for Concentrating Solar Thermal Power Plants to generate as much electricity as is currently consumed by the World (17,000 TWh/y), by Europe (EU-25, 3,200 TWh/y) and by MENA (600 TWh/y), respectively. The square labelled "TRANS-CSP Mix 2050" indicates the space needed for solar collectors to supply the needs for seawater desalination and about two-thirds of the electricity consumption in MENA in the year 2050 and about one-fifth of the European electricity consumption by Concentrating Solar Thermal Power Plants (2,940 TWh/y in total).

Source: desertec.org

Problems:

- Efficient energy conversion solar energy/energy carrier
- Efficient energy transport potentially over large distances
- Economy based on energy cycle of renewable carriers

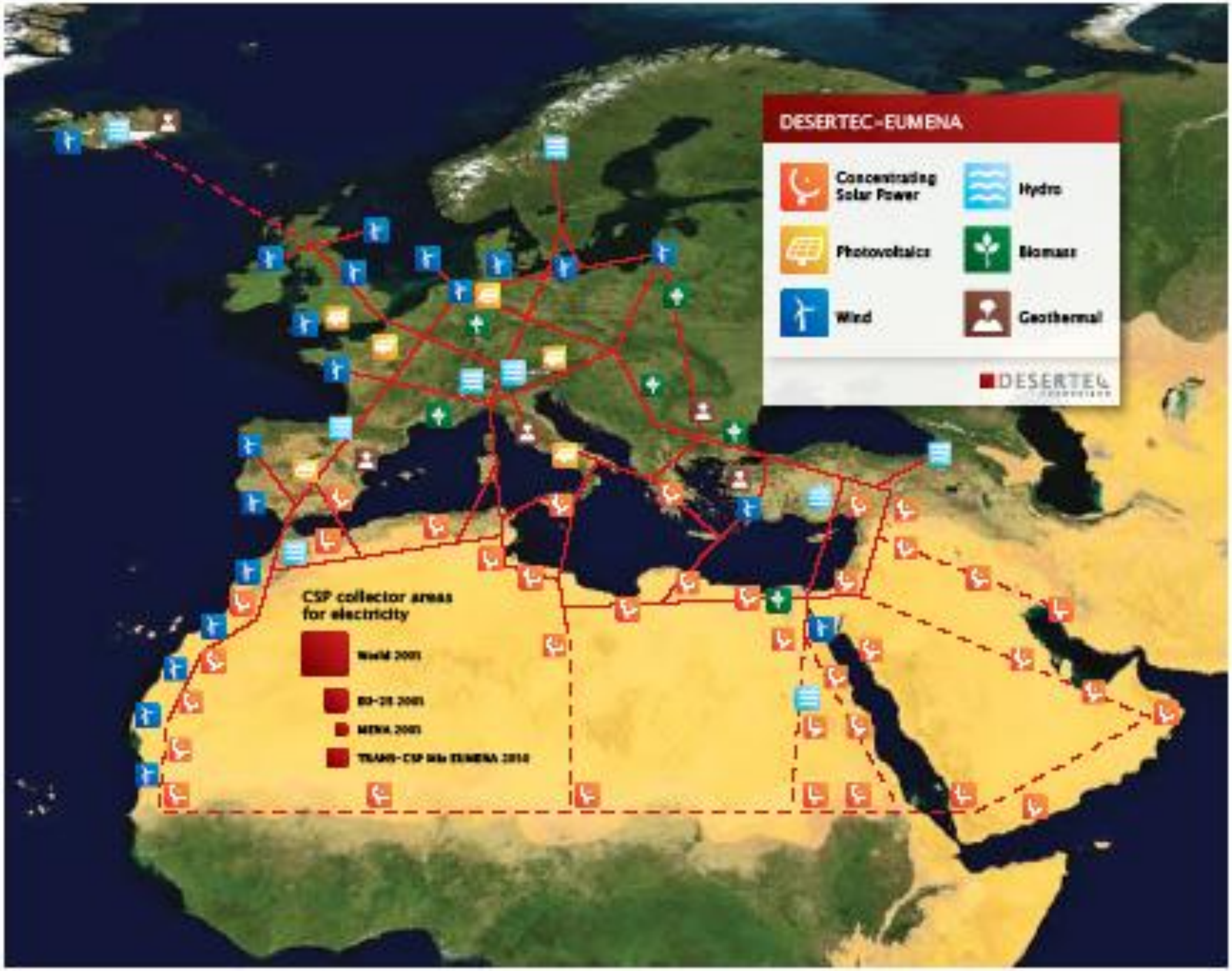
Potential sources of renewable energy



Solar energy by fare the most abundant energy source

Source: German Space Agency DLR

European Energy Network



Methods of energy conversion

Concentrating solar power (known as CSP):

Power generation of CSP: about 100 MW/km^2

Solid state solar cells

Direct conversion of sunlight into electric power via semiconductor thin films

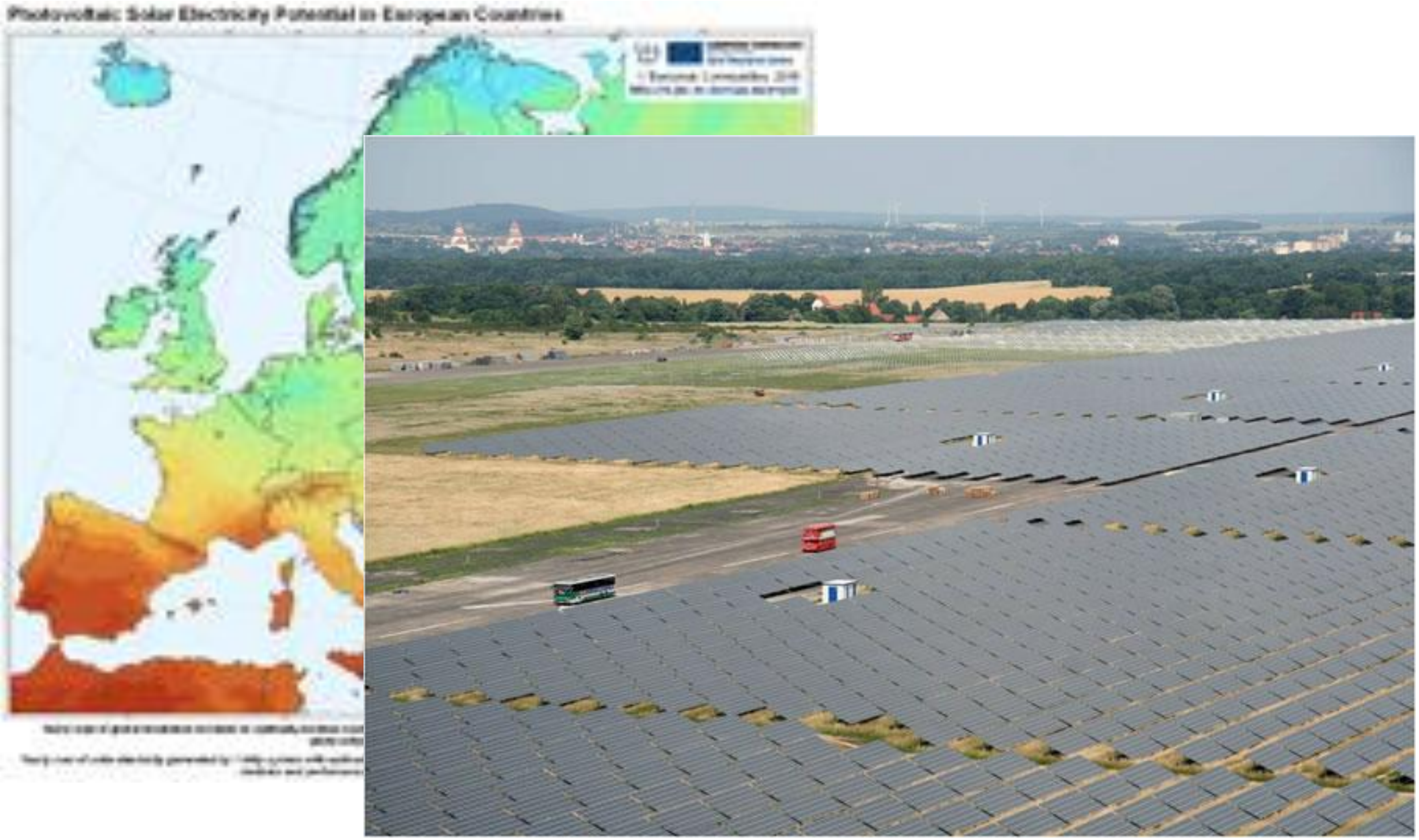
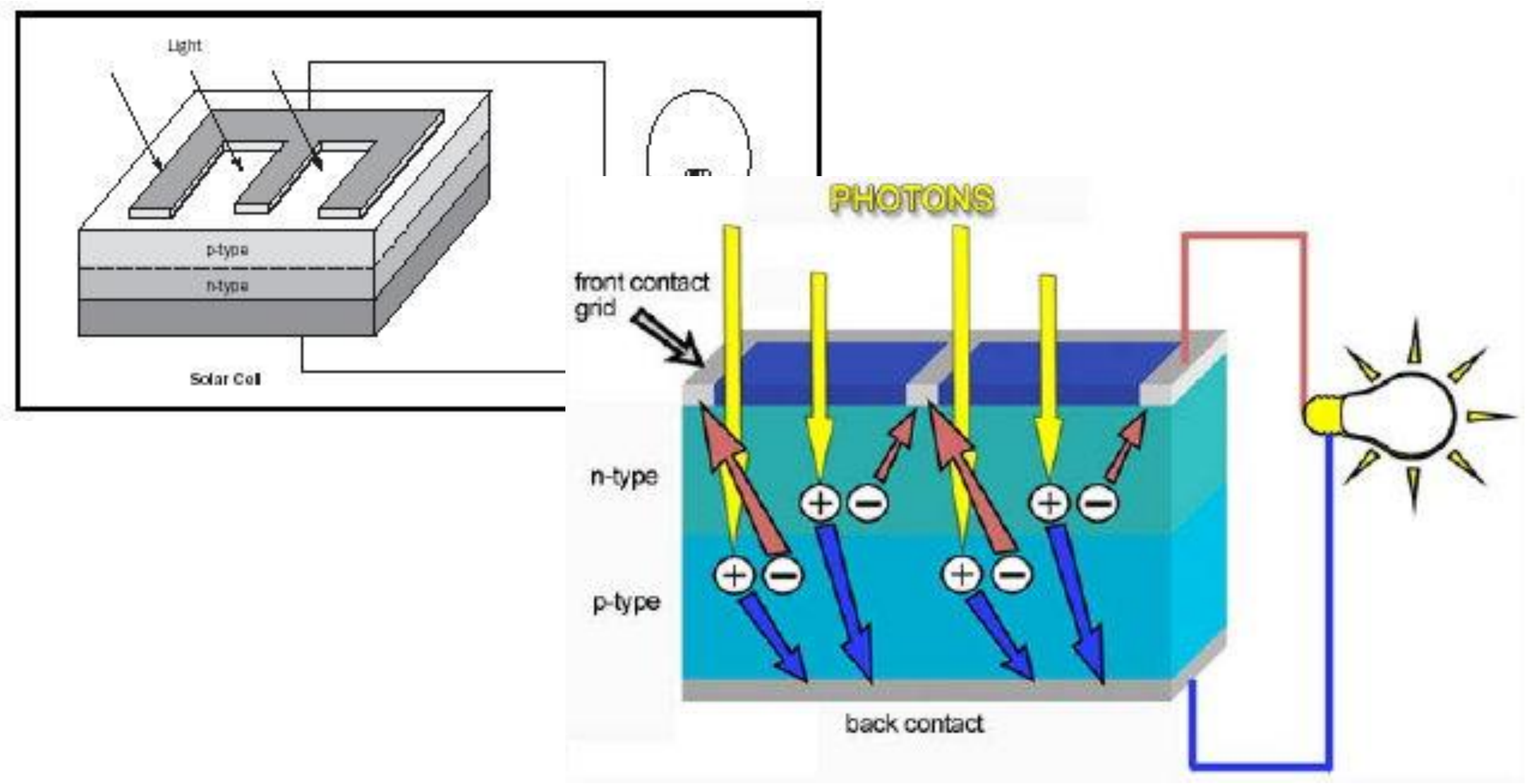


Image: Photovoltaic power station with a capacity of 40MW in eastern Germany

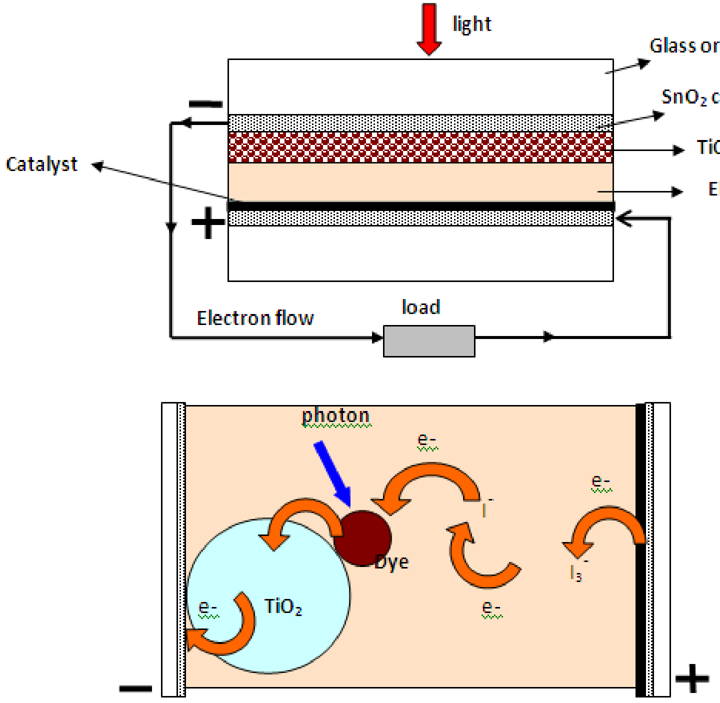
Photovoltaics: the principle (pn junction)



The pn-junction provides an inbuilt potential of about 0.6 – 0.7V, the excitation of electrons into the conduction band provides the current
Efficiency of semiconductor (Si, CdTe, GaAs) cells: ~ 20%

Industrial applications

Polycrystalline semiconductor cells



PV dye cell schematics

Dye-sensitized TiO_2 cells

Nature 414, 338 (2001)

Problems of solar cells

- Semiconductor solar cells:
  - Energy balance of production
  - Cost of production material
  - Frequency dependence of light adsorption
- Dye sensitized cells
  - Lifetime of dye compounds
  - Efficiency of cells
  - Frequency dependence of light adsorption

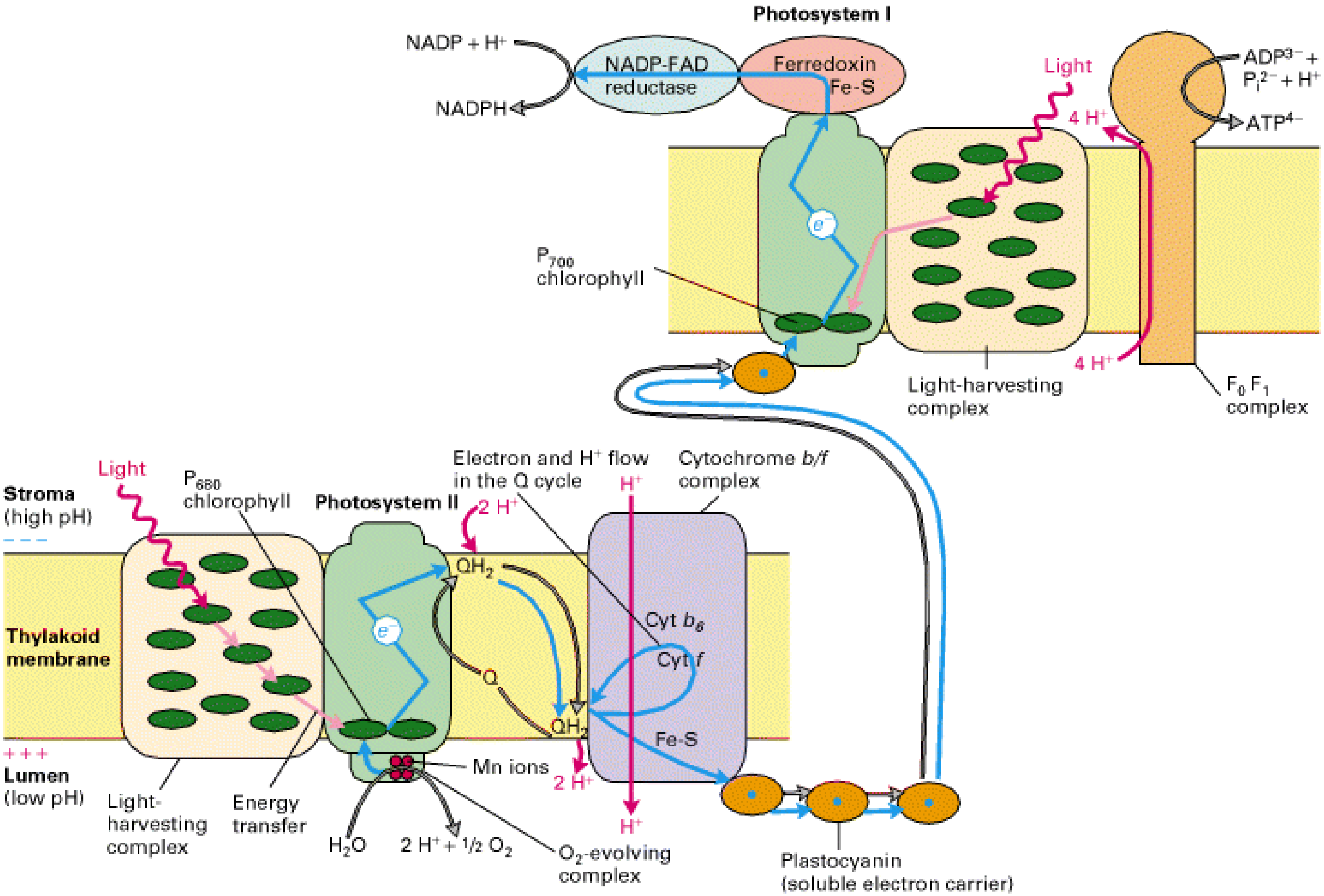
Bottom line: photovoltaics will not be the exclusive solution to our energy problems

Photosynthesis

Oldest and most ubiquitous method of energy conversion:

Efficiency higher than 50%

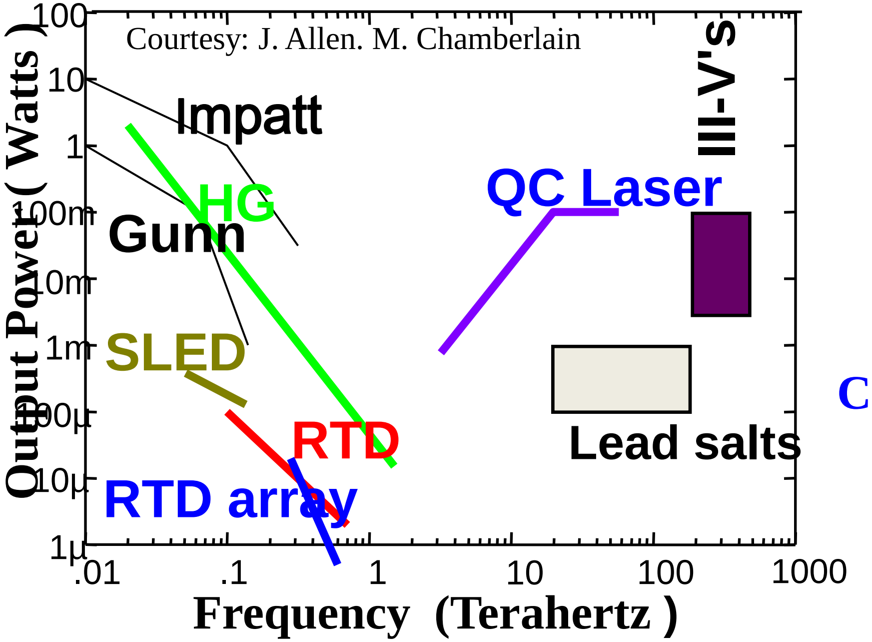
Photosynthesis: the principle



Main ingredients: electron separation and transport
oxidation/reduction of organic compounds

from wikipedia

Accelerator Sources of Terahertz Radiation



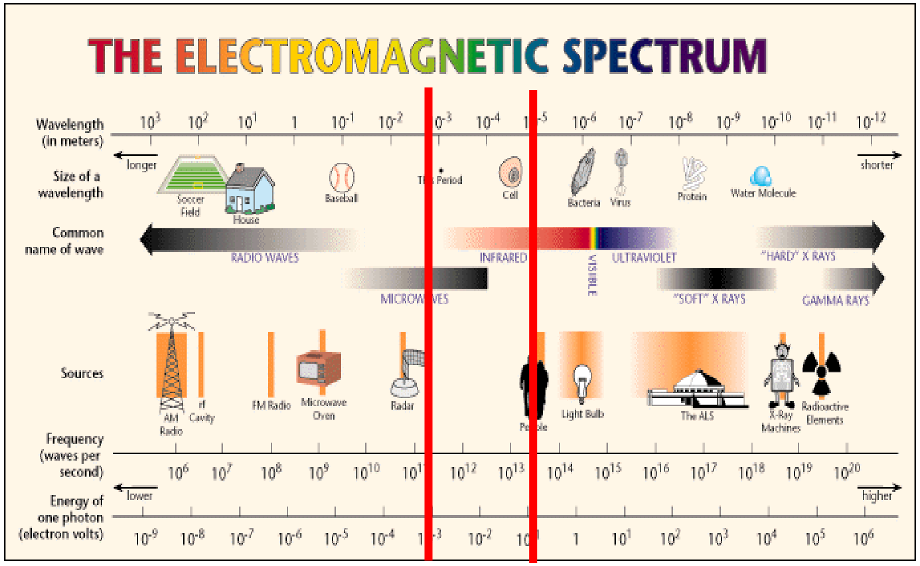
Power of laboratory instruments

At 1 THz ~ 100 μ watts

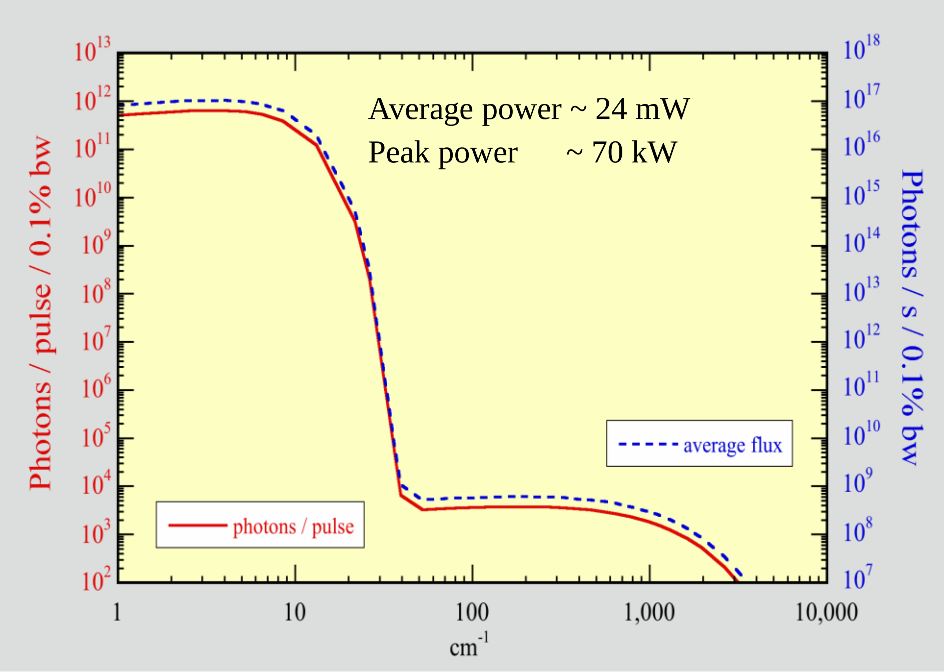
Short electron bunches

When bunch length < wavelength

Coherent emission ---> massive output power

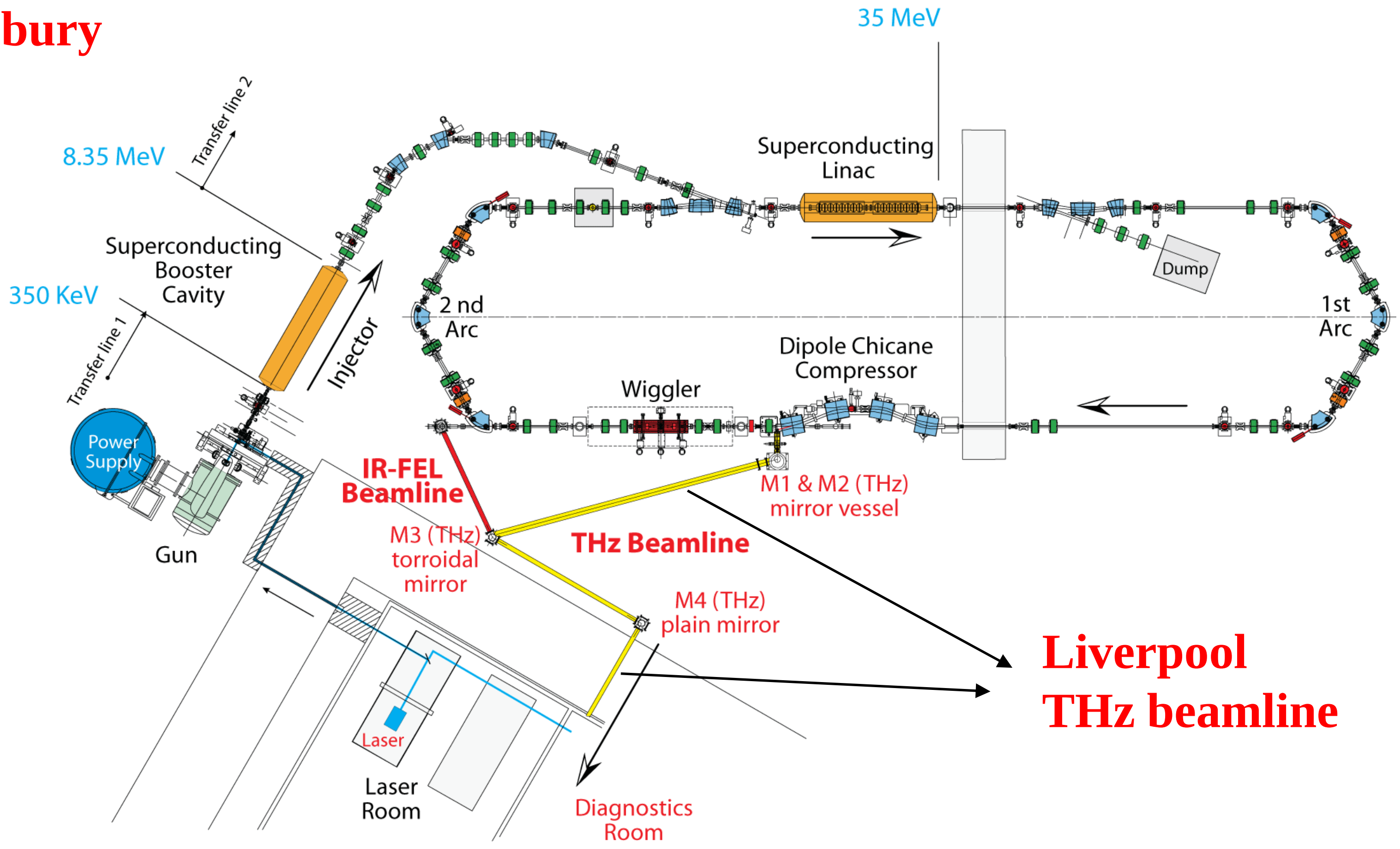


Daresbury ERLP/ALICE



Energy Recovery Linear Accelerator / ALICE

Daresbury



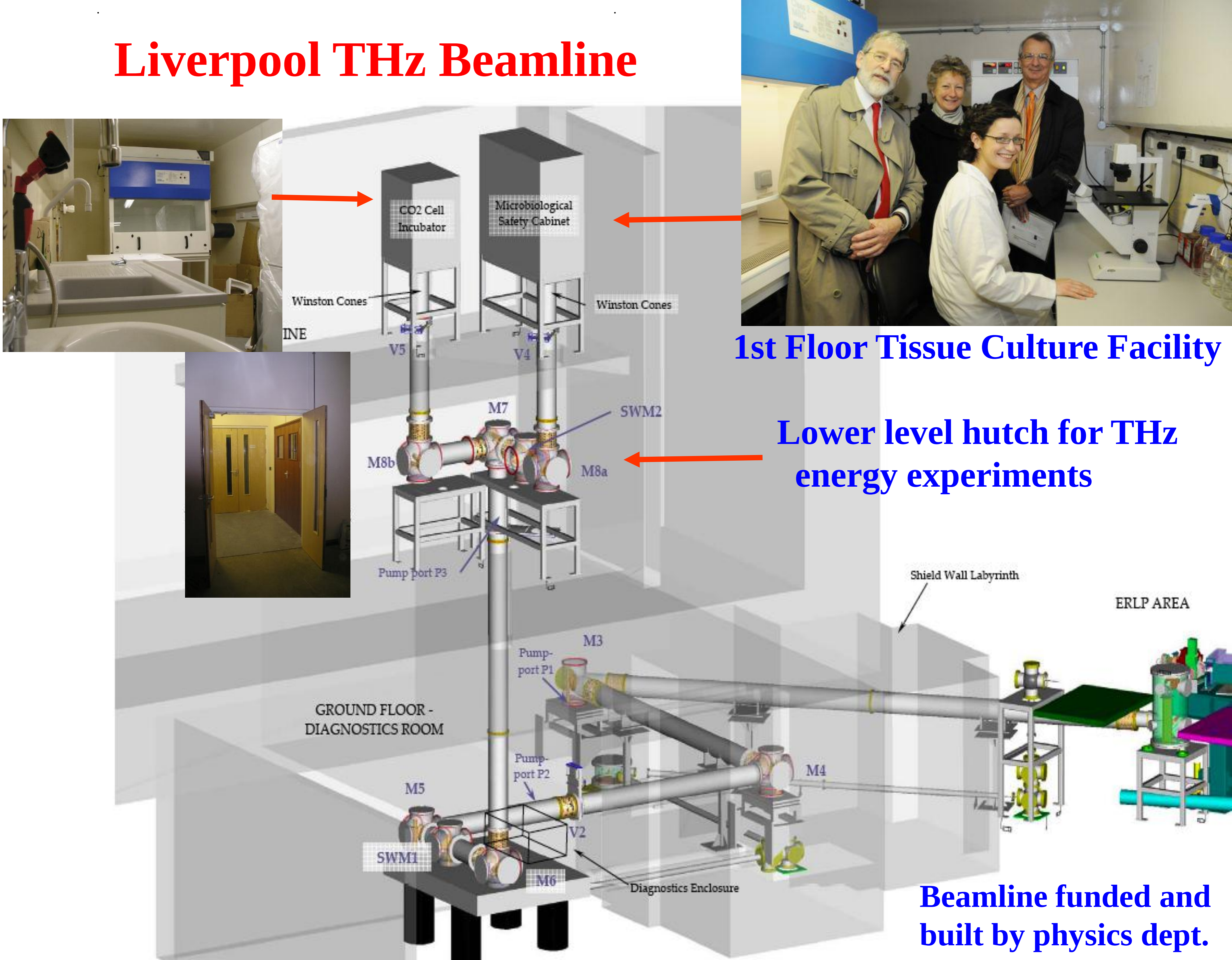
Liverpool THz beamline

NW Science Fund: Liverpool

The most intense broad band source of THz in Europe and only the 3rd in the world.

5 years under construction now commissioning

Liverpool THz Beamline



1st Floor Tissue Culture Facility

Lower level hutch for THz energy experiments

Beamline funded and built by physics dept.

Artificial Photosynthesis

Key elements:

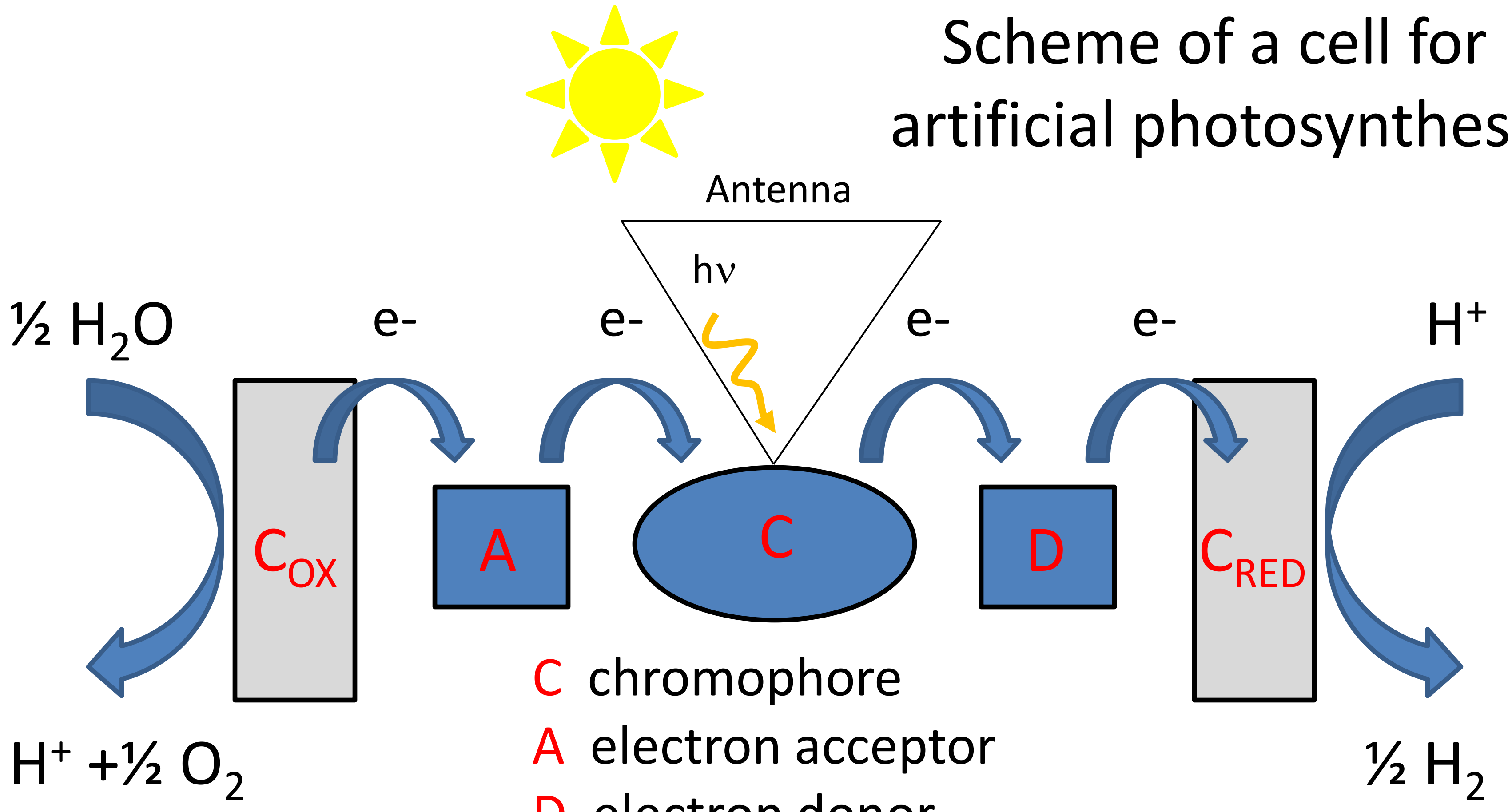
- A photo receptor, often a metal complex
    - Function: adsorb photons and release excited electrons
- A transducer, often organic ligands
    - Function: transport electrons from the photo receptor to the catalytic reactor
- A catalytic reactor, also often a metal complex

So why hasn’t this been done already?

Short answer: it turns out to be rather difficult.

But the good news is: we know that it works.

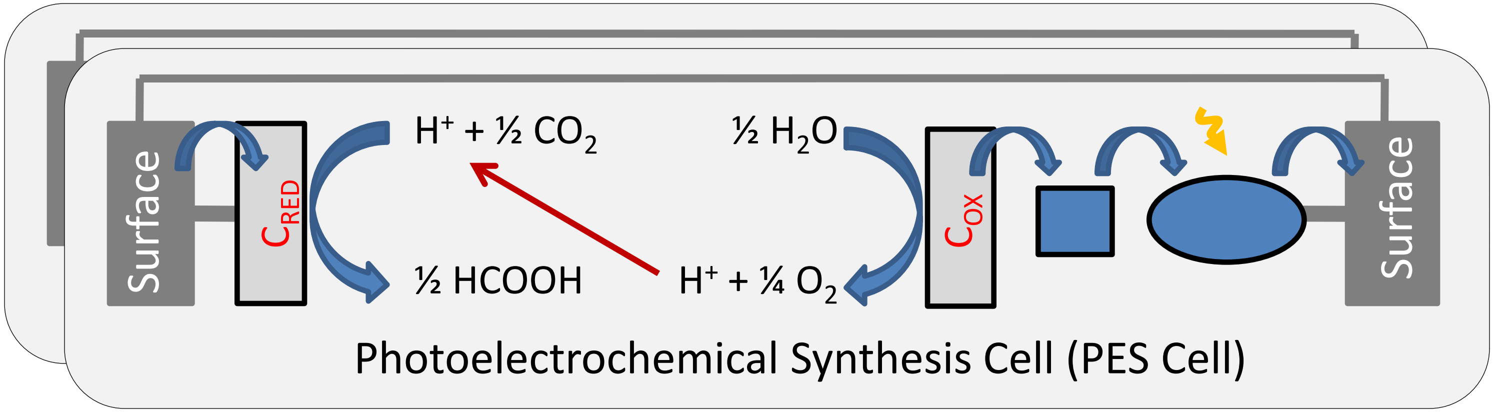
Scheme of a cell for artificial photosynthesis



C chromophore

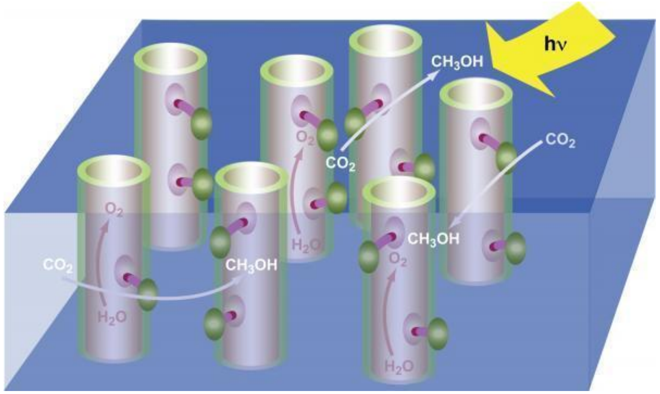
A electron acceptor

D electron donor



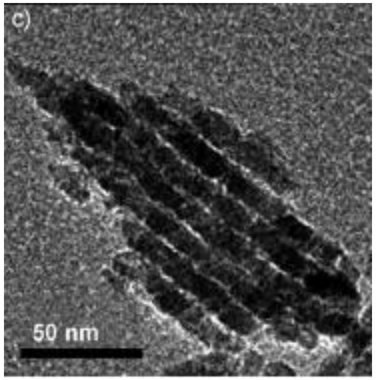
Photoelectrochemical Synthesis Cell (PES Cell)

Recent advances

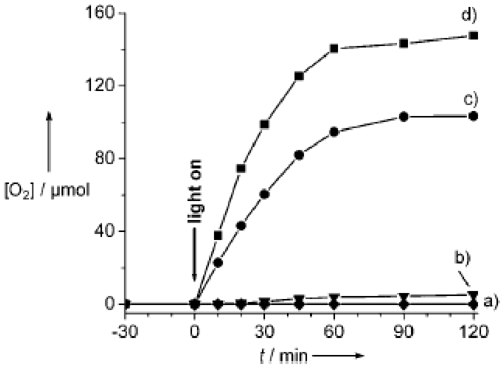


Scheme: nanostructured materials (here, nanotubes) are used to convert CO_2 in solution into methanol

TEM image of the clusters



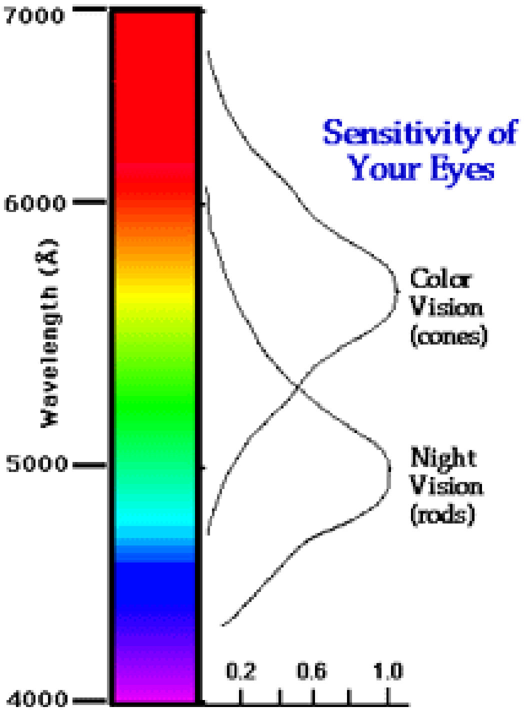
Oxygen formation



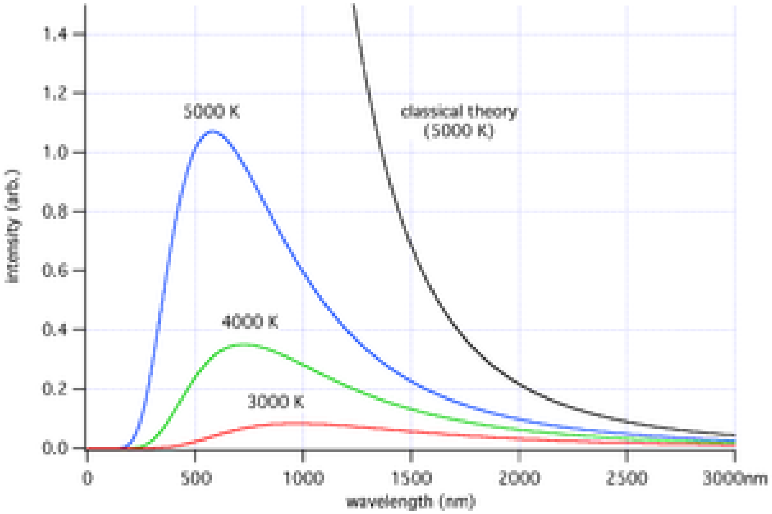
First steps: photo-oxidation of water in Cobalt oxide nanoclusters

F. Jiao and H. Frei, Angewandte Chemie Intl. Ed. **48**, 1841 (2009)

Solar spectrum and material properties



E ~ 1.8 eV



E ~ 3.1 eV

Needed: a semiconductor with a bandgap of less than 1.8 eV and fast carrier transport for charge separation: metal oxides and/or metal organic compounds

Metal oxide nanotubes: preliminary results

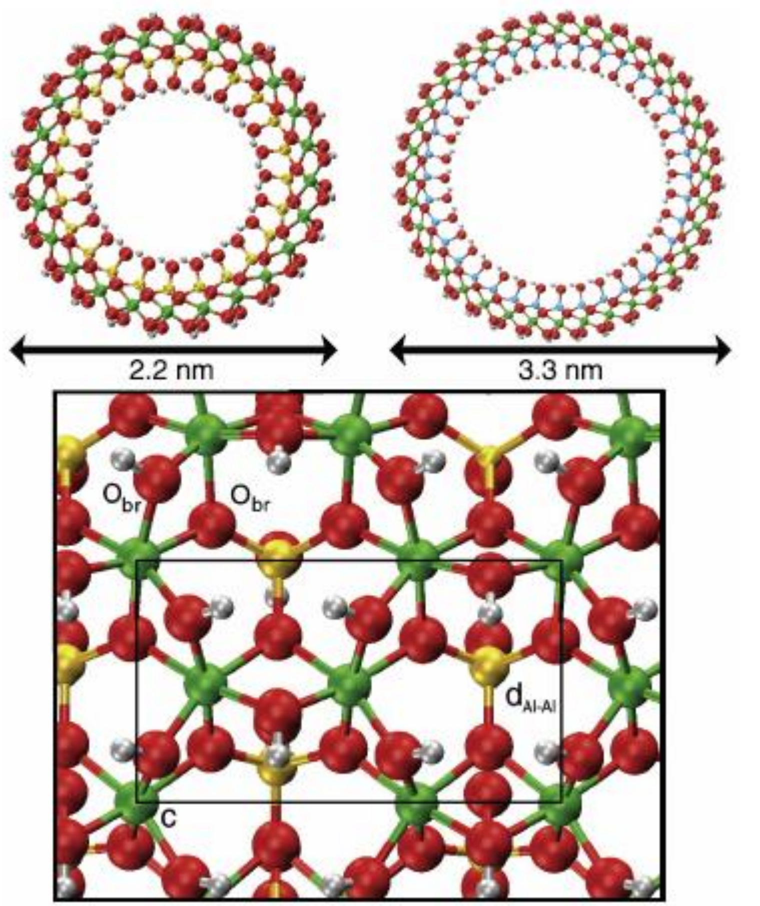


Figure 1. Optimized geometrical structure of $(Al_2SiO_7H_4)_{24}$ (left) and $(Al_2GeO_7H_4)_{36}$ (right) based nanotubes. The single-wall structural motif (bottom) is displayed together with the zig-zag periodic unit of size $\{c, d_{Al-Al}\}$ along the nanotube axis and circumference. Electronic version: O, red; H, grey; Al, green; Si, yellow; Ge, cyan.

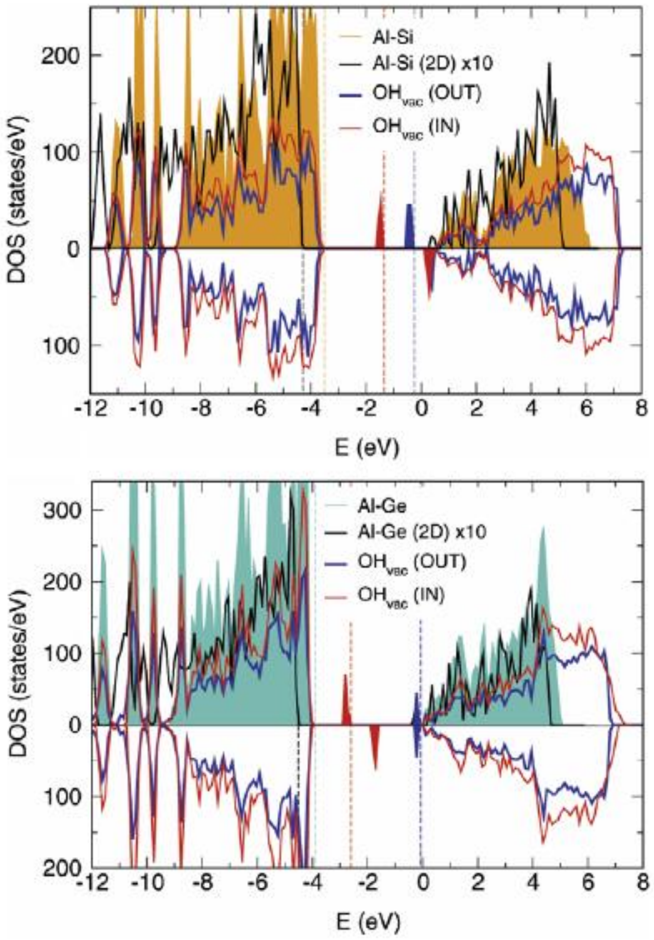
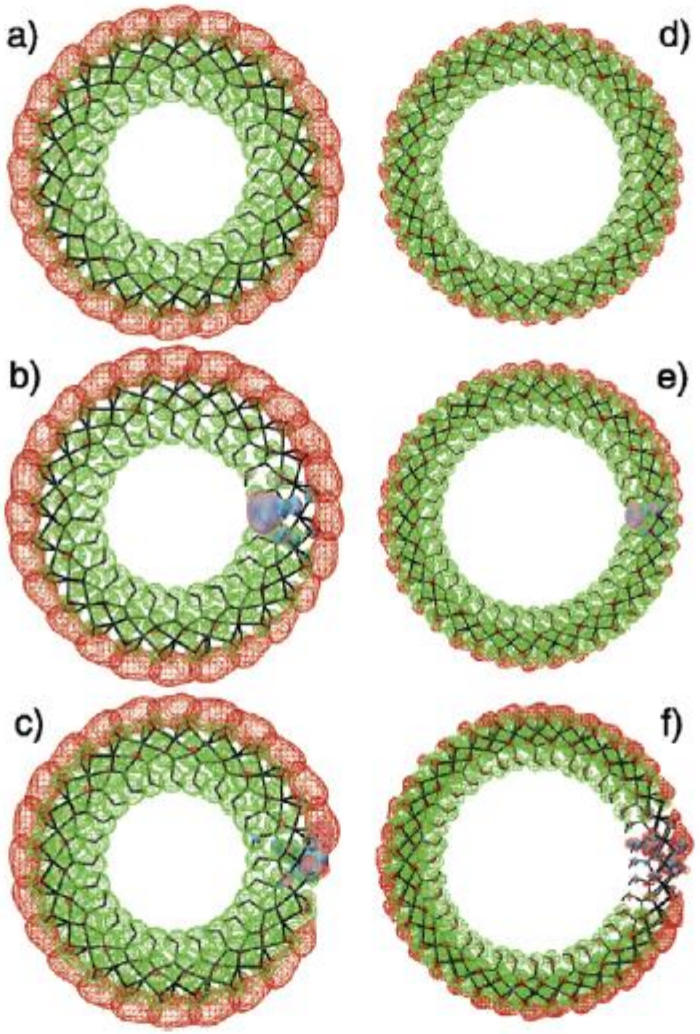


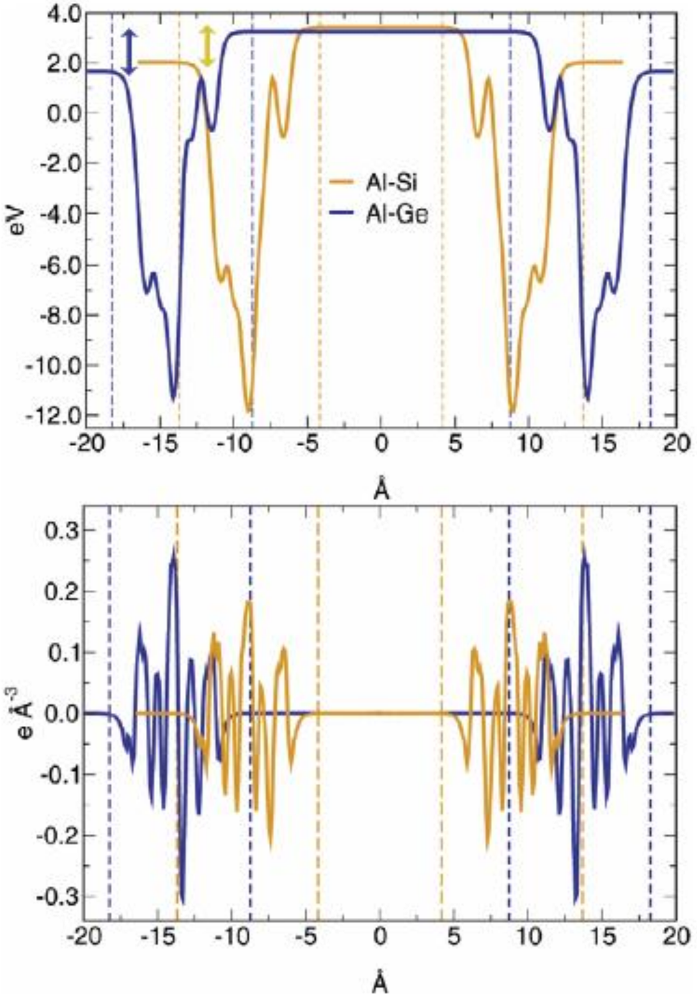
Figure 4. Total density of states (DOS) for defect-free Al–Si and Al–Ge, their 2D analogues, and in the presence of one OH_{vac} both on the outer (OUT) and the inner (IN) surface of the tubes. Calculated Fermi energies are displayed as a dotted line with the same colour labelling as for the DOS. 2D and band gap defect states (filled) have been increased by a factor of 10 for clarity.

JPCM 21, 195301 (2009)

Charge polarization and membrane

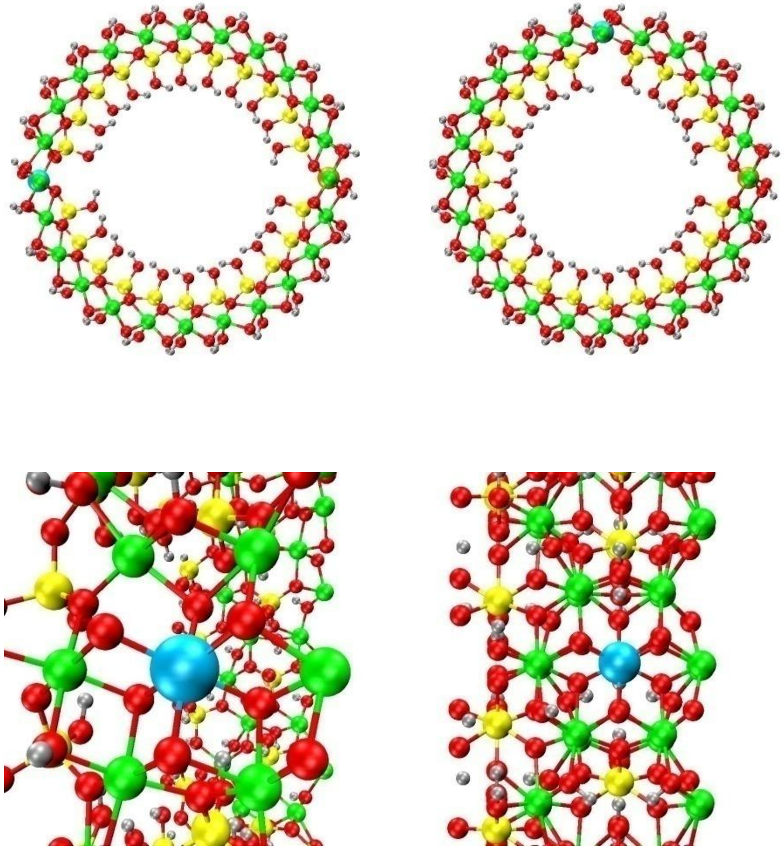


Charge separation: green valence band
red conduction band

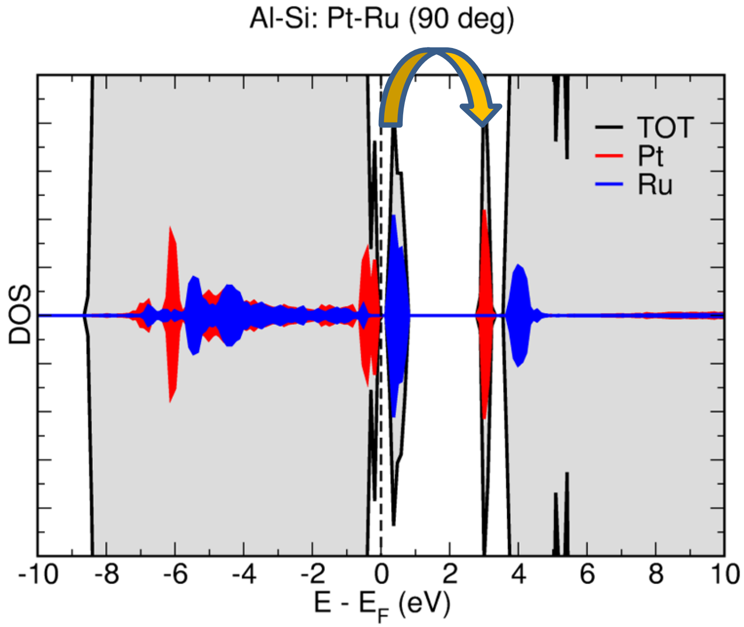


Electrostatic potential and
Charge density: radial dipole field

Metallic adsorption and reaction centres



Dopants: Ru, Pt



Bandgap for Ru -> Pt less than 2 eV

Fundamentally new material for photosynthesis applications